Potential Methods for Permitting Connector Resonance at 32GT/s

Steve Krooswyk
Signal Integrity Engineer
(New Product Development)
Samtec

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Acknowledgement

- **Madhumitha Rengarajan**

  Signal Integrity Engineer

  (New Product Development)

Outline

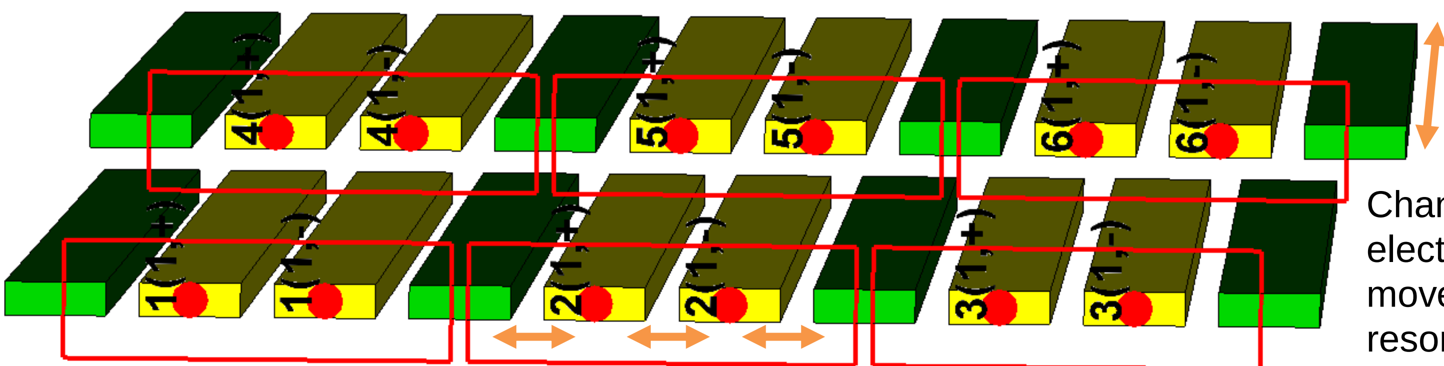
- **Presentation Objective**
- **Problem Statement**
- **Demonstration of Problem Statement**
  - Introduction to a Resonant 3D Structure
  - Resonating vs. Non-resonating structure
- **Possible Connector Crosstalk Evaluation Metrics**
- **Evaluation of Two Proposed Metrics**
  - Integrated Crosstalk Noise (ICN)
  - Crosstalk PDF at BER
- **Summary of Results**

Problem Statement

- **Presence of crosstalk resonances related to connector height**
  - Always been present in PCIe® channels – but now appear in the operating band at 32GT/s
- **Resonances may create excursions beyond the frequency domain specifications typically used for connector qualification**
- **Excursions, that are narrow in band and insignificant in magnitude, may not impact the system performance**
- **In a system, many non-CEM form-factors are compared against the PCIe mask with even lower resonant frequency**
  - For example, longer length of PCIe right angle or edge mount connectors
- **Rigid limits that do not allow insignificant excursions lead to:**
  - False-negatives
  - Component over-design
  - Exclusion of many connectors from the PCIe signal path

Demonstration of Problem Statement: Resonant 3D Structures

"Connector-like" 3D resonant structure proposed

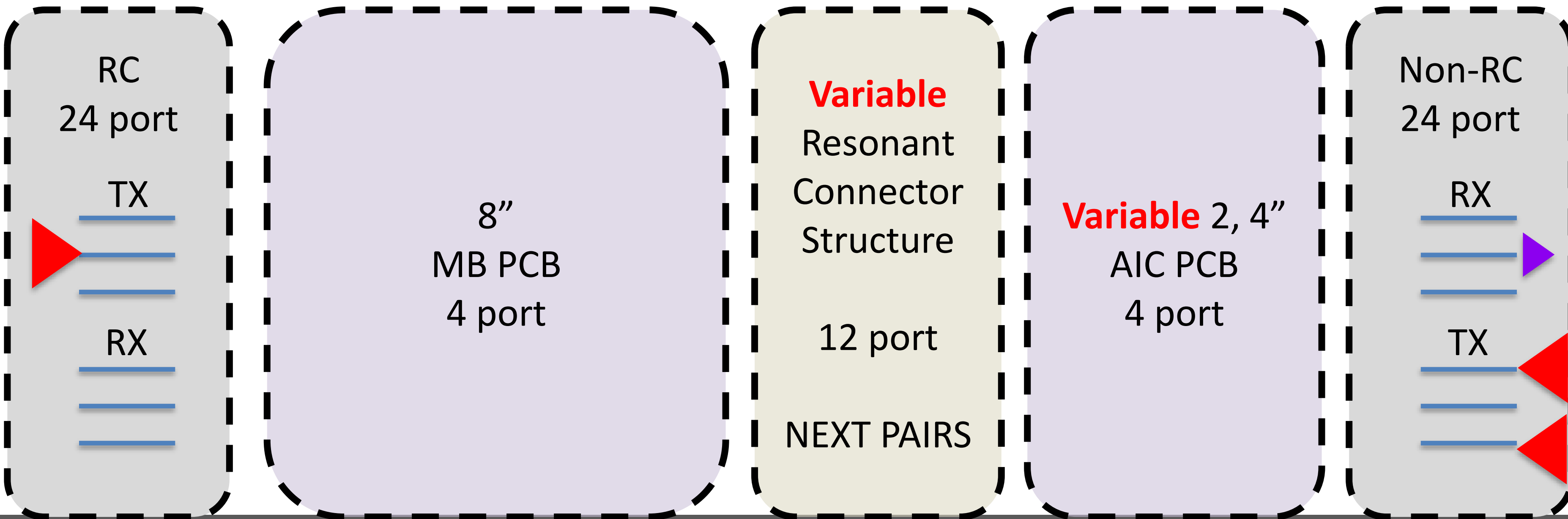


Changing the electrical length moves the XT resonance in frequency

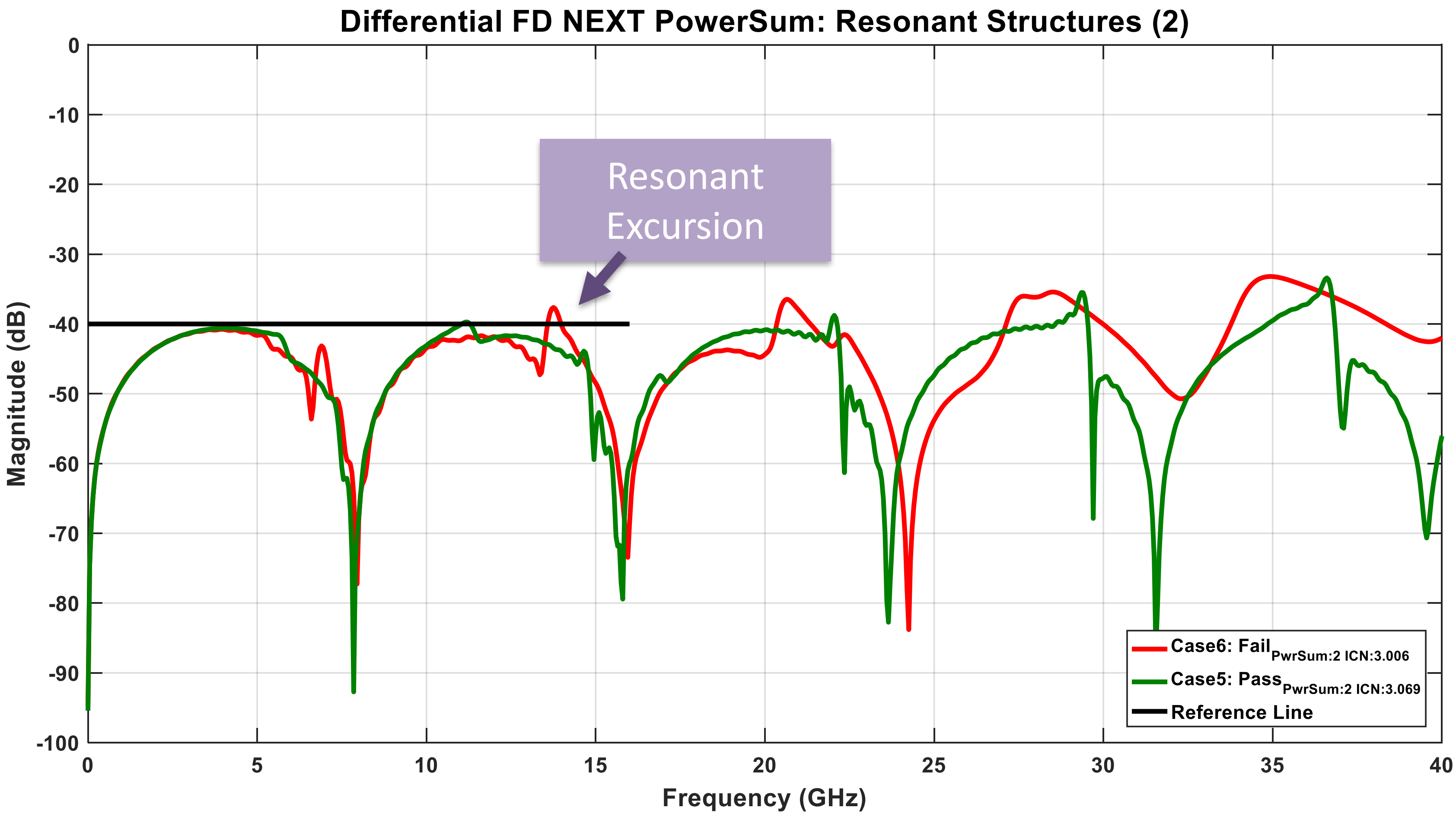
S:S and S:G separation relates to crosstalk magnitude

Channel Topology – Seasim

- **Two Variables: Connector crosstalk and AIC Length**
- **Prelim 32GT/s Reference packages**
- **Supply two NEXT aggressors as the most interesting case – sensitive to AIC length**
- **Connector IL\RL is artificially held constant to focus on crosstalk alone**
  - Reality they are linked – more simulation could be done

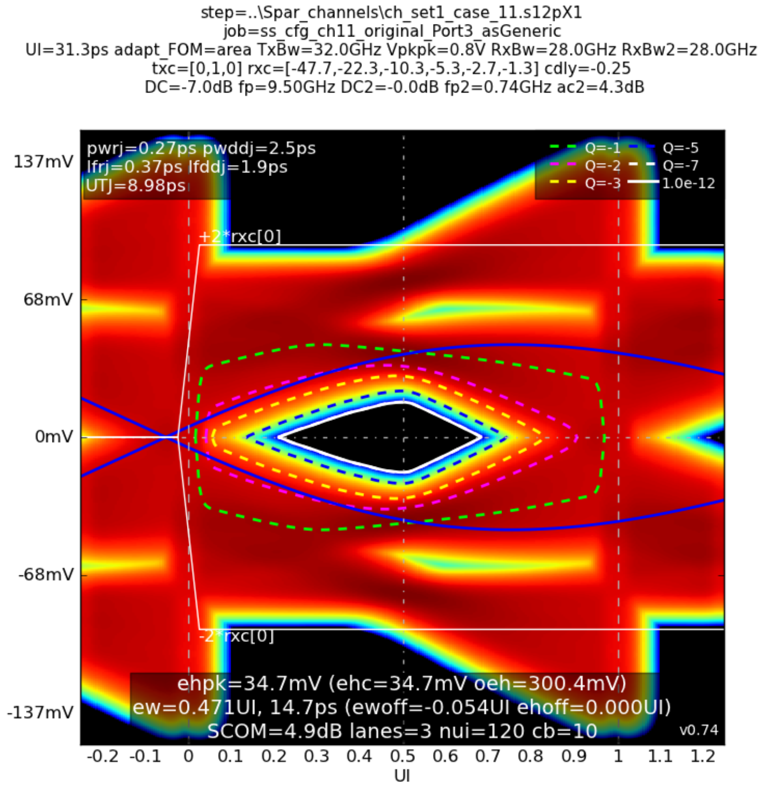


Example #1: Excursion at 14GHz

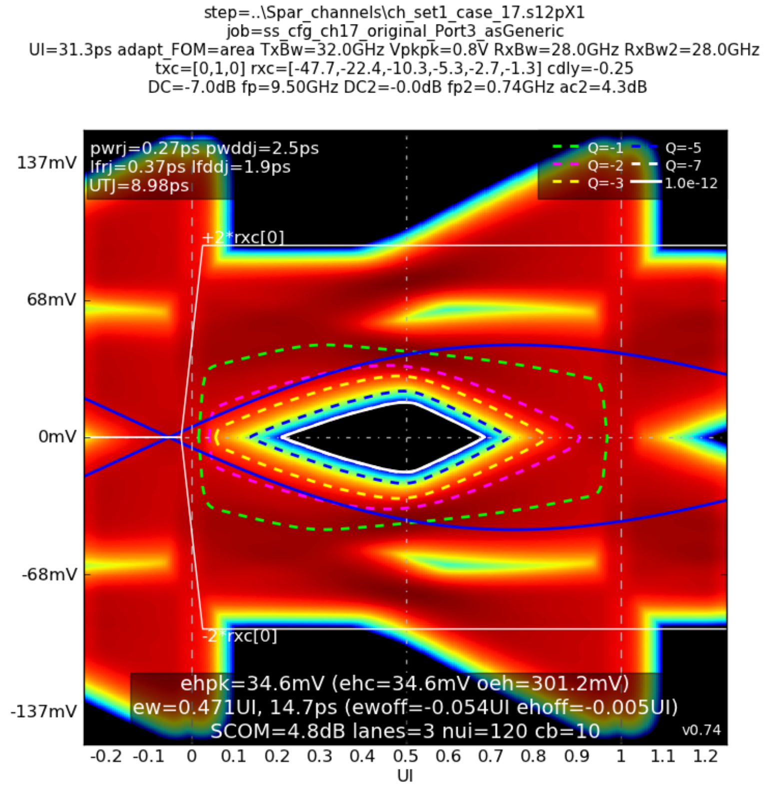


Example #1: This Excursion is Negligible

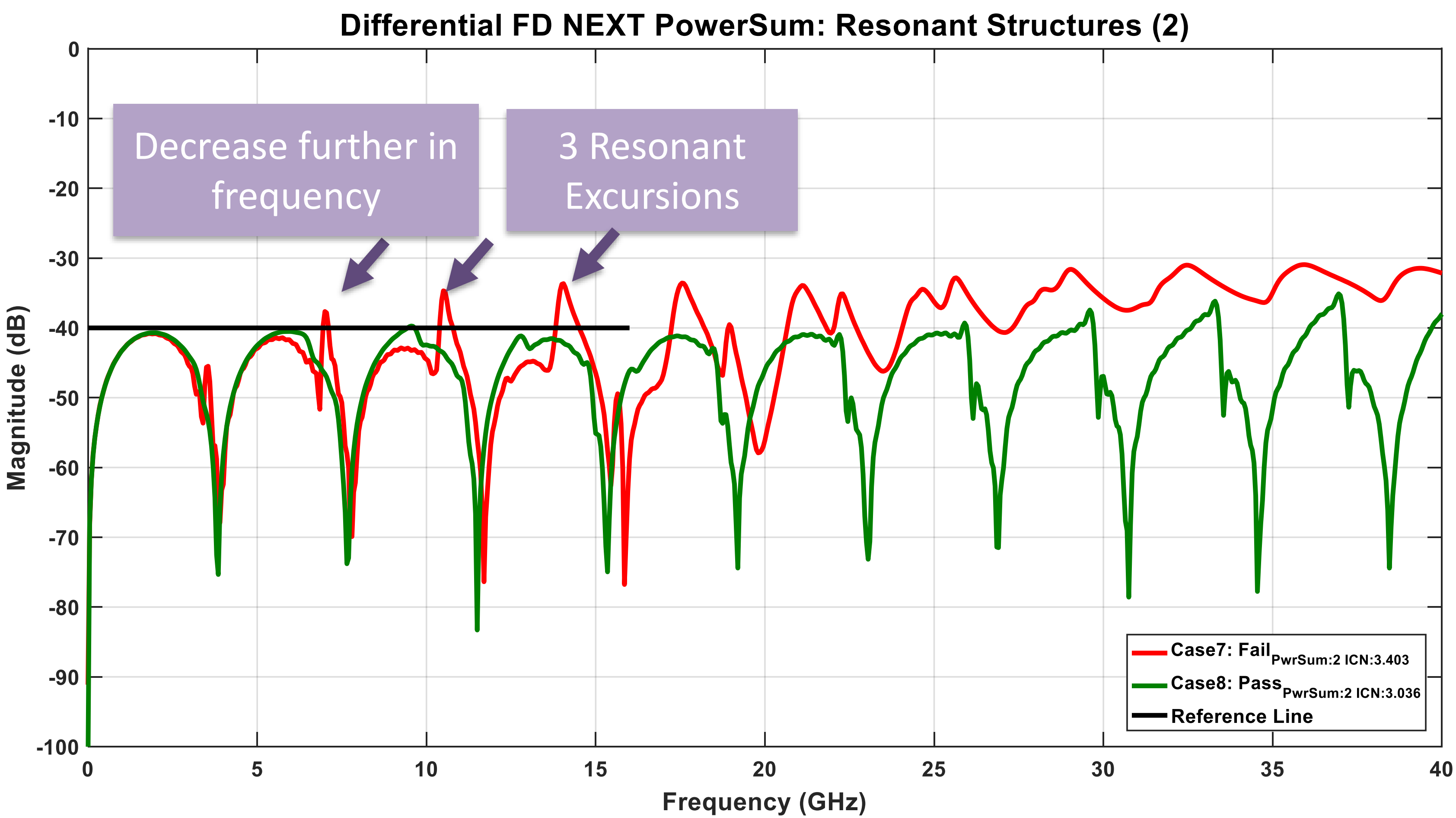
No Excursion



With Excursion

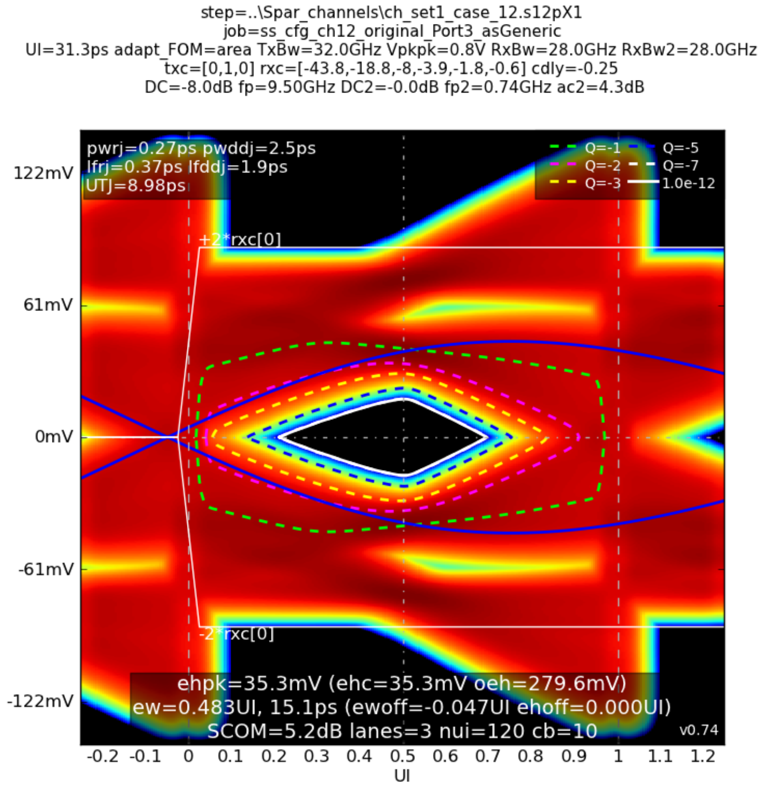


Example #2: More Excursions and Lower Frequency

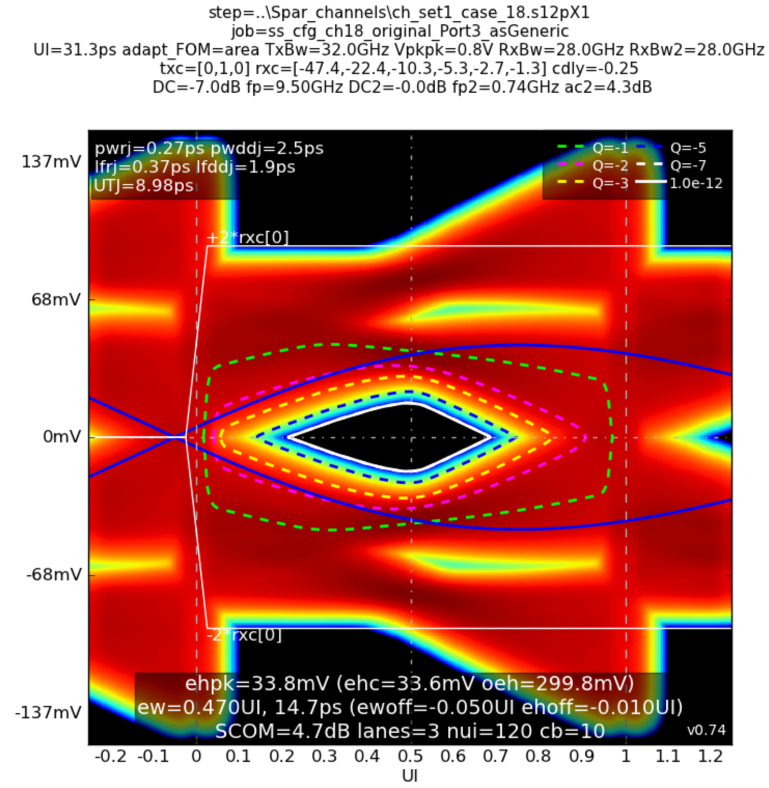


Example #2: Still Fairly Negligible

No Excursion

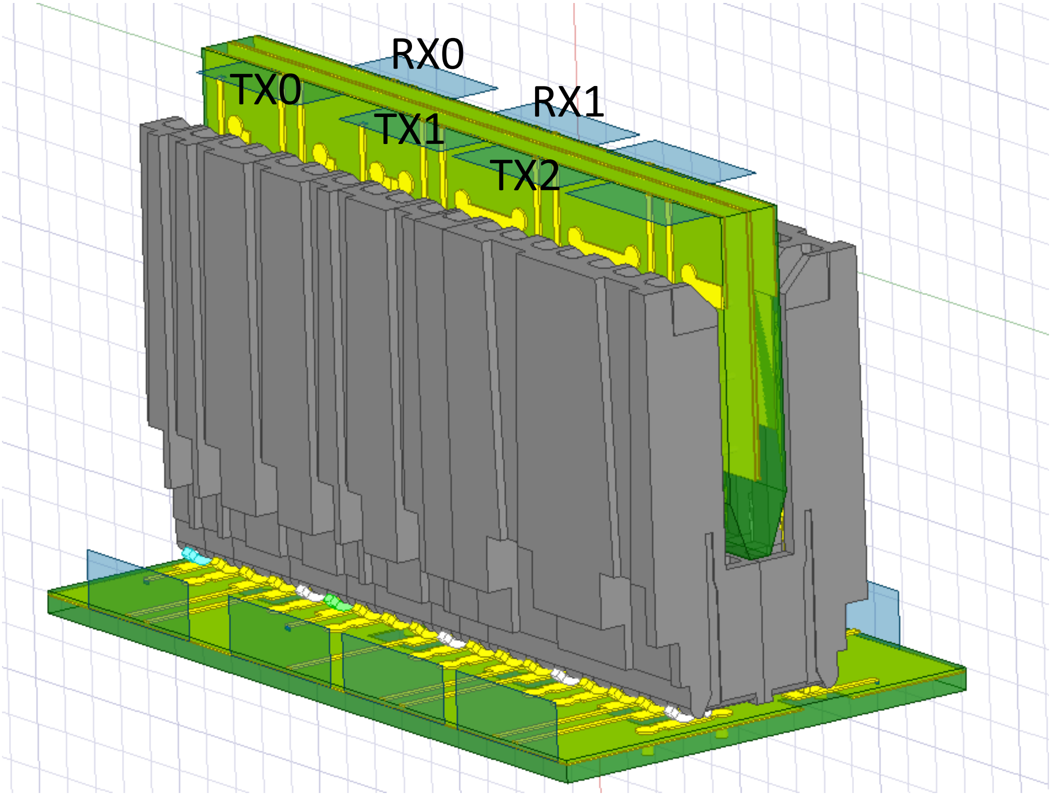


3 Excursions



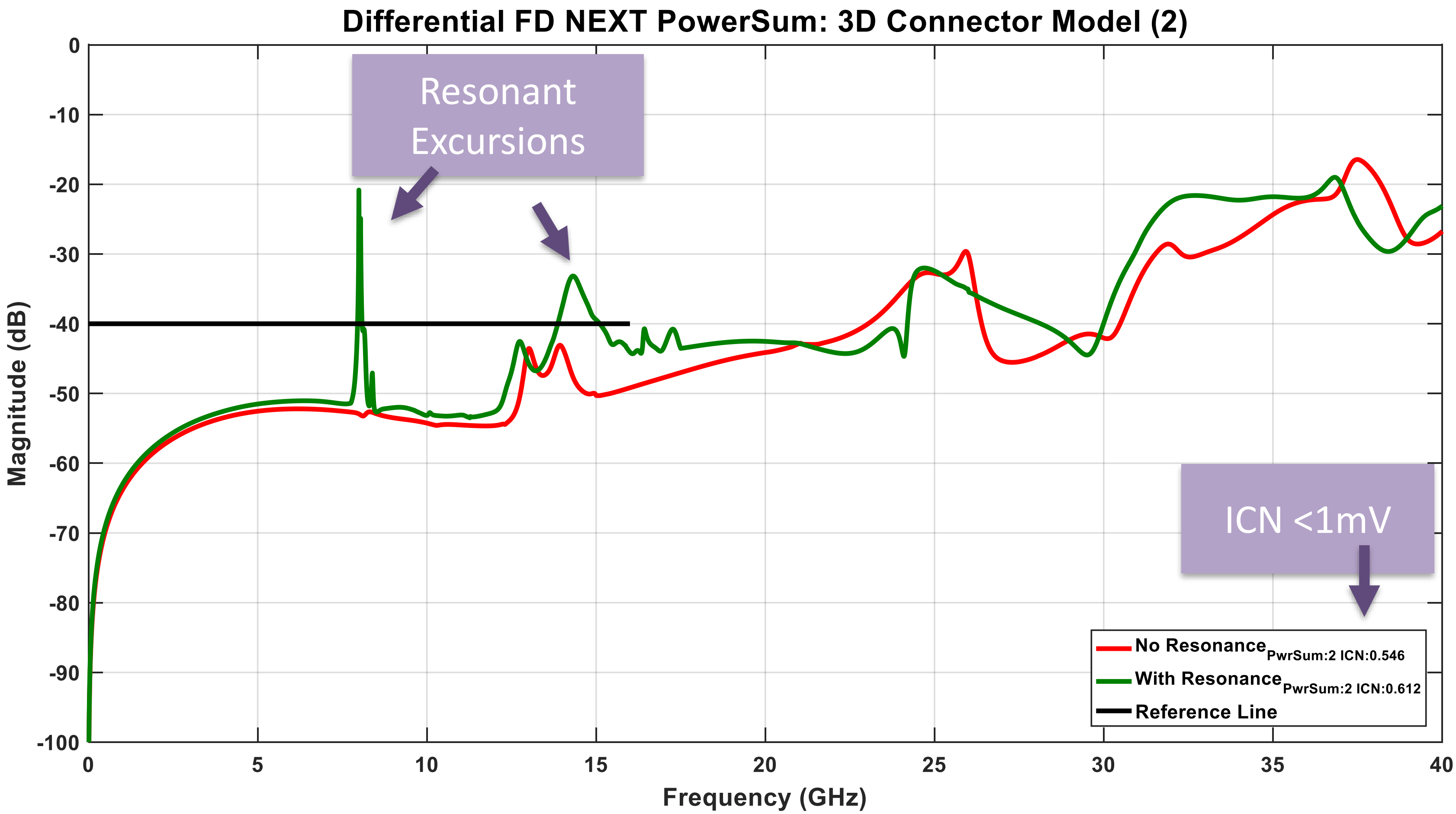
Example #3: Connector Model

- **32GT/s Edge Card Concept**



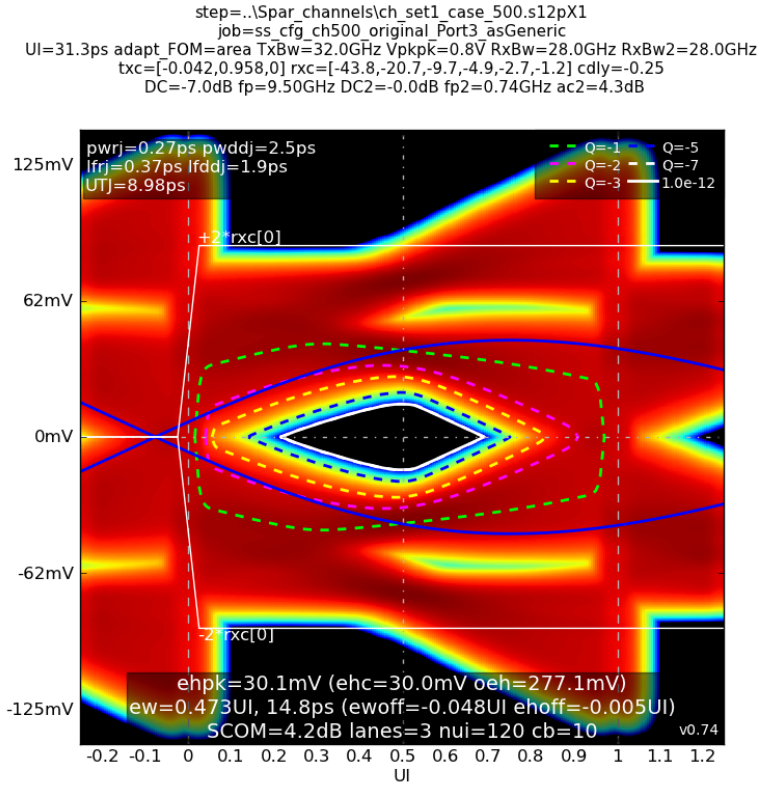
PCIe-G5-XXX

Example #3: Connector Model Early and Later Concepts

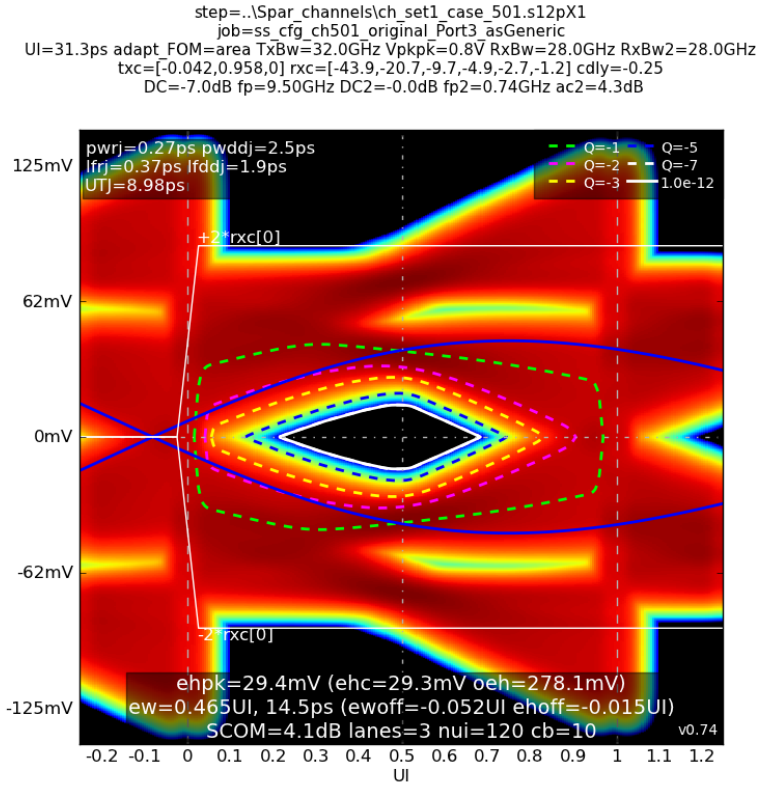


Example #3: Still Fairly Negligible

No Excursion

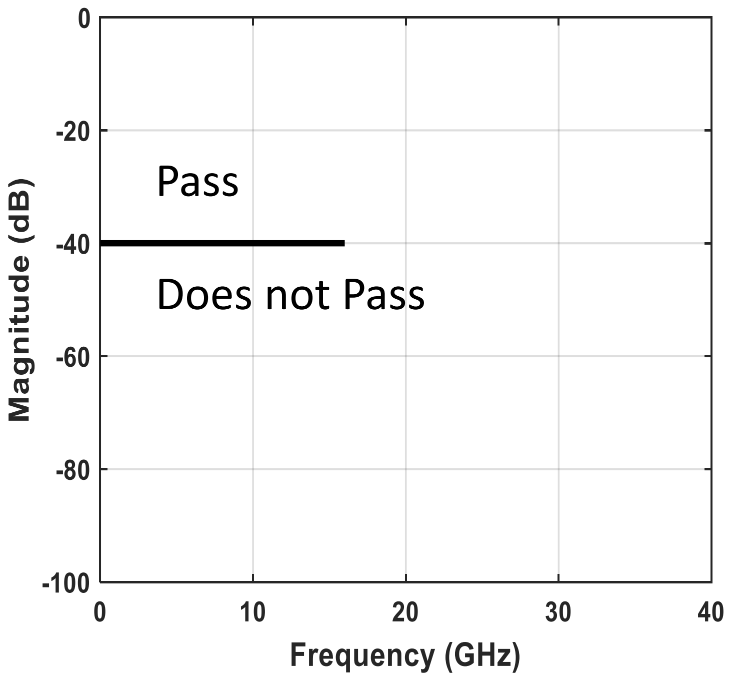


Excursions



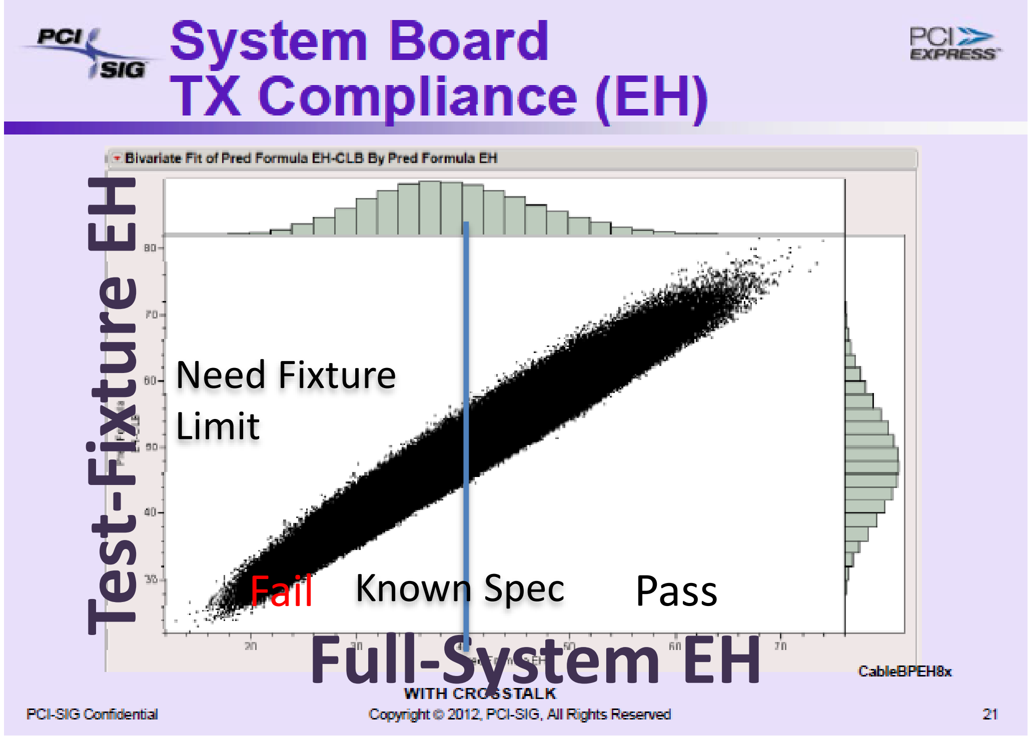
Do we need a frequency domain mask at 32GT/s?

- FD Masks can be black and white: Pass or Not
- It has been suggested that 30% of mask failures are due to resonance
- Not sure if masks have been correlated to EH and EW
  - Relate a continuous to a Boolean?



Let's Consider CEM System and Card Compliance

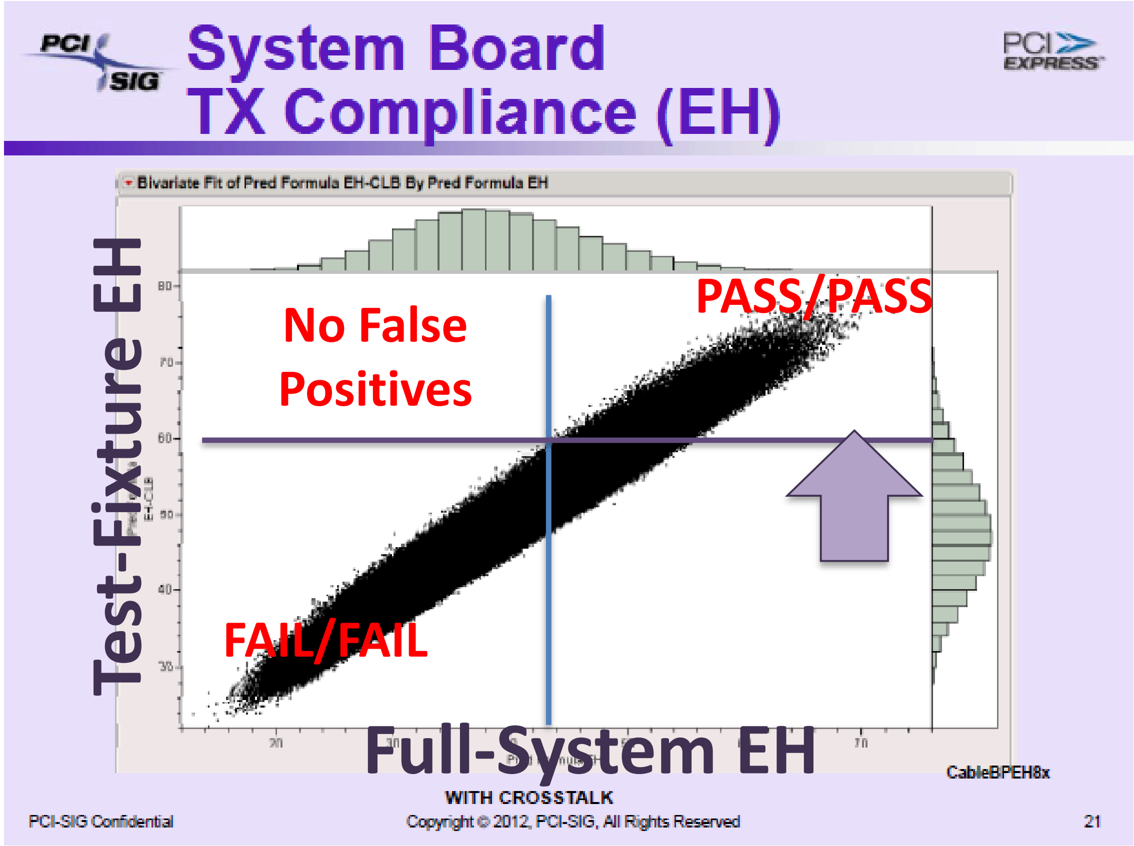
- **A single number relates two domains that we want to correlate**
  - System EH to Fixture EH



A single number allows the balance to be determined… between over and under design, and more or less scrap

A Single Metric Permits Risk Trade Off

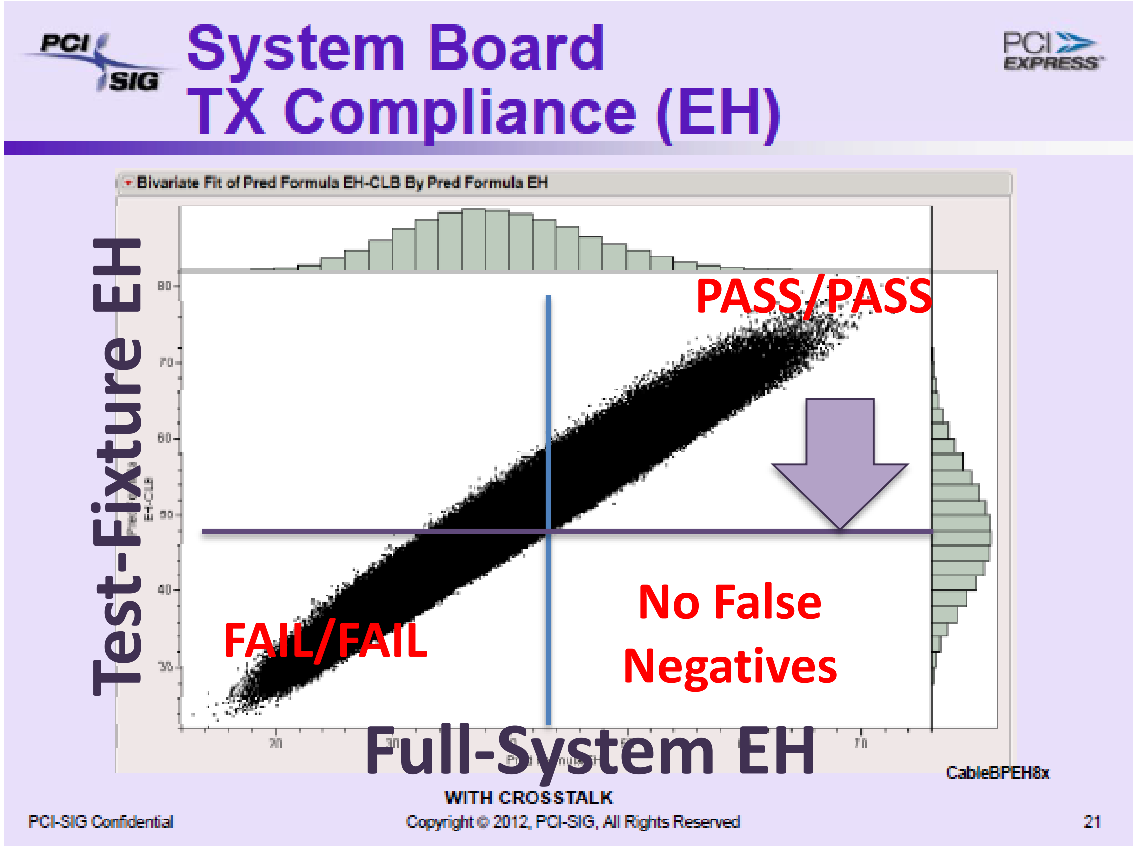
Relationship Between Full-System and Test-Fixture PCIe 3.0



We can choose to raise this line and decrease system risk

A Single Metric Permits Risk Trade Off

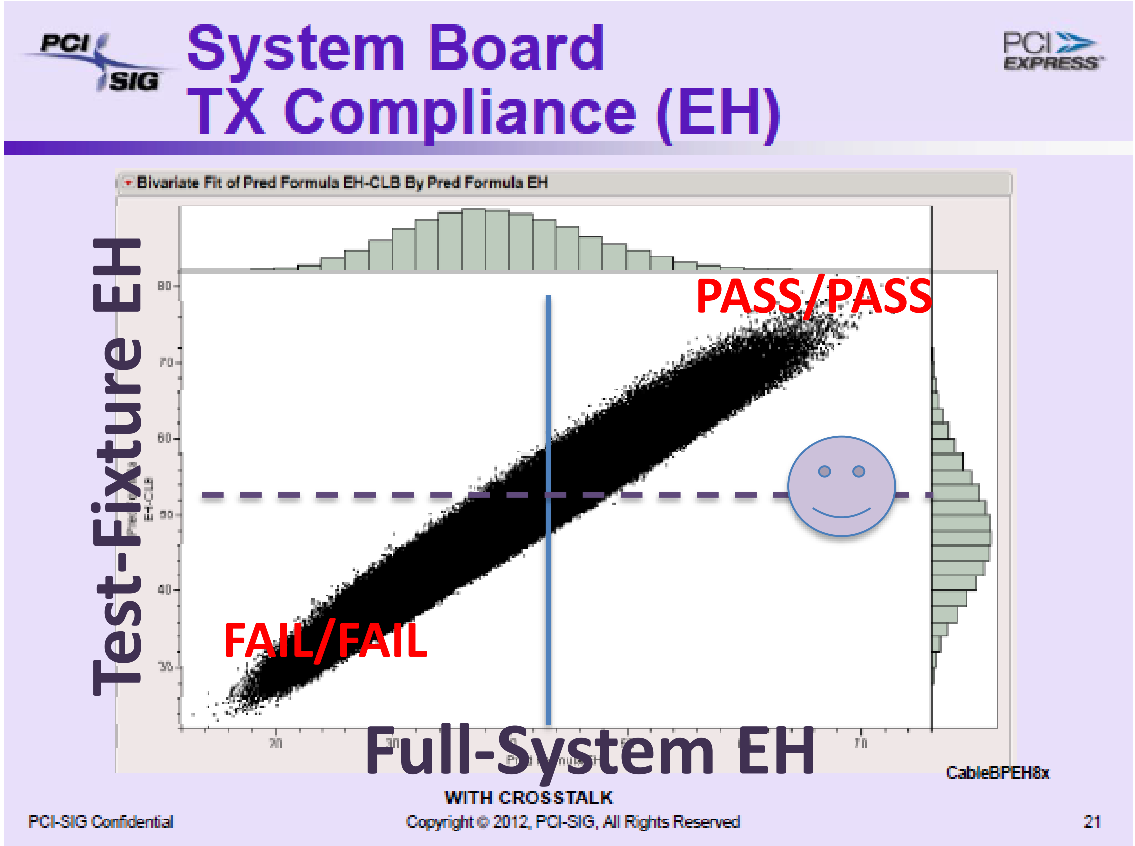
Relationship Between Full-System and Test-Fixture PCIe 3.0



Or we can choose to lower this line and reduce "scrap"

A Single Metric Permits Risk Trade Off

Relationship Between Full-System and Test-Fixture PCIe 3.0



Or we can balance the risk

Difficult to do this with a mask

Possible Connector Evaluation Metrics

- **Reference Channel Simulation**
- **Excursion Area Integration**
- **Spectral Weighted Metrics**

Possible Connector Evaluation Metrics

- **Reference Channel Simulation**
- **Excursion Area Integration**
- **Spectral Weighted Metrics**

Reference Channel

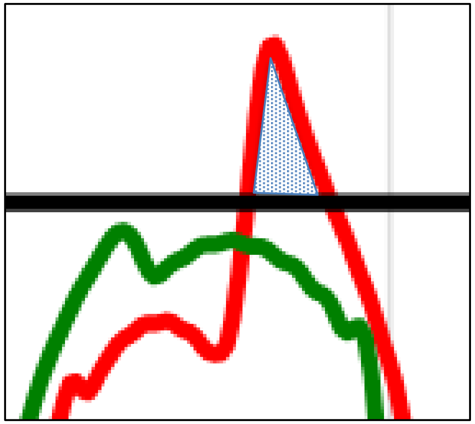
- **Evaluate connector DUT in a standardized channel**
- **Would establish a minimum EH and EW**
- **Standardized tool (Seasim)**
- **Channel would be crosstalk-free**
  - Cancelation with channel crosstalk can make DUT look better!
- **Attraction: Includes all aspect of connector IL, RL, and XTALK at once**
- **Concerns:**
  - Heavy post processing of s-parameters
  - Combine many S4P measurements into 12-24P
  - Interpolation and frequency range standards
  - Measurement quality suitable for time domain conversion
  - Competing de-embedding standards

Possible Connector Evaluation Metrics

- Reference Channel Simulation
- **Excursion Area Integration**
- Spectral Weighted Metrics

Excursion Area Integration

- **Integrate excursion area above reference line**
- **Define a maximum excursion area**
  - Or a ratio of excursion to non-excursion area



- **Attraction: Easy to compute, less change from existing methods**
- **Concerns:**
  - Does not relate to the physical (correlation will be poor)
  - All magnitudes carry the same weight
  - No spectral weighting – could use a filter

Possible Connector Evaluation Metrics

- Reference Channel Simulation
- Excursion Area Integration
- **Spectral Weighted Metrics**

Proposed Metrics for Connector Evaluation

- **Authors propose the following metrics for connector evaluation:**
  - Integrated Crosstalk Noise (ICN)
  - Crosstalk PDF at BER of Interest

Metric #1: Integrated Crosstalk Noise (ICN)

- **Integration of power-weighted crosstalk power-sum**
- **ICN has been done before**
  - Cable assembly specifications
  - Connector test measurements[1]
- **System inputs to the power weighting function will drive better correlation**
  - TX rise time and RX bandwidth are configurable
  - Different scalars for FEXT and NEXT
- **Agnostic to measurement step size choice**
- **More tolerant to noise**
- **Equation implementation is straight forward for test equipment**

$$PWF(f) = UI \cdot sinc(UI \cdot f)^2 \cdot \left(\frac{1}{1+\left(f\frac{T_r}{0.2365}\right)^4}\right) \cdot \left(\frac{1}{1+\left(\frac{f}{F_{RX}}\right)^8}\right)$$

$$\sigma_{icn} = \sqrt{2 \cdot \Delta f \cdot \sum_n PWF(f_n) \cdot \sum_x A_x^2 \cdot |SDD21XTK_x(f_n)|^2}$$

Where:

UI – Unit interval (s)

f – Nyquist frequency (Hz)

Tr – Transmitted (20-80)% Risetime (s)

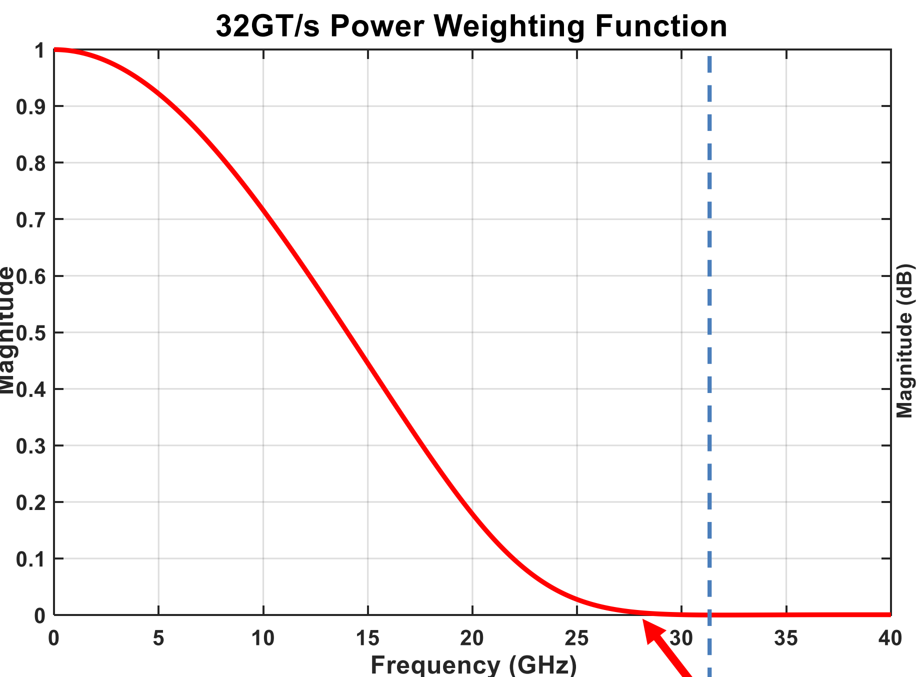
F_{RX} – 3 dB receiver bandwidth (Hz)

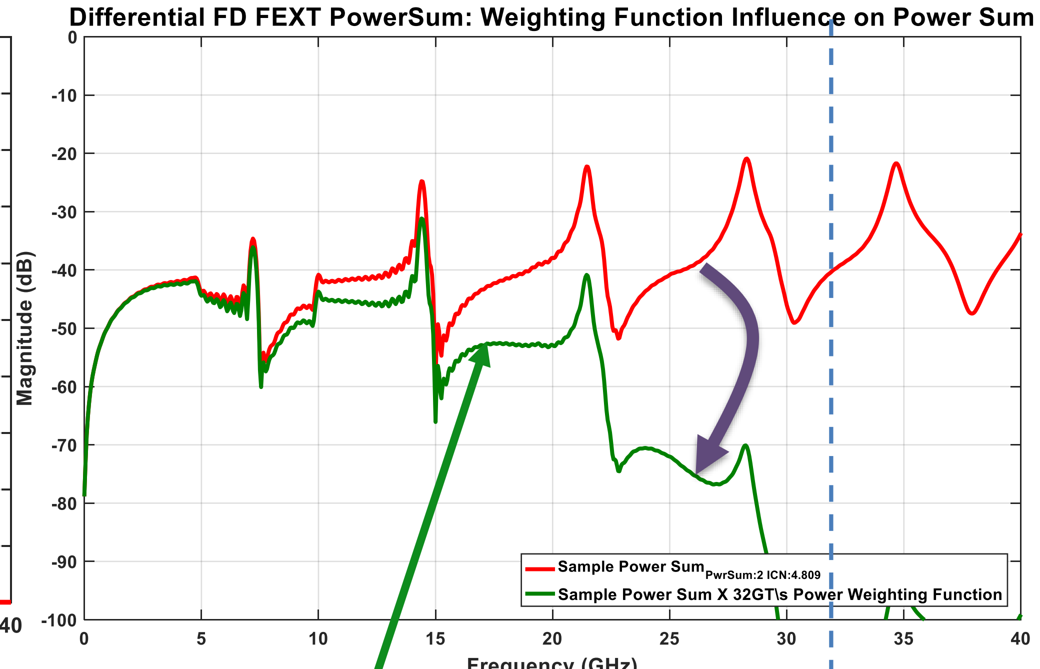
A_x – Amplitude of the crosstalk aggressors (V)

Δf – Frequency step (Hz)

1. https://ibis.org/summits/nov12a/dong.pdf

Metric #1: ICN
Intermediate Components of ICN





Weighting function goes to zero at 2 x Nyquist frequency

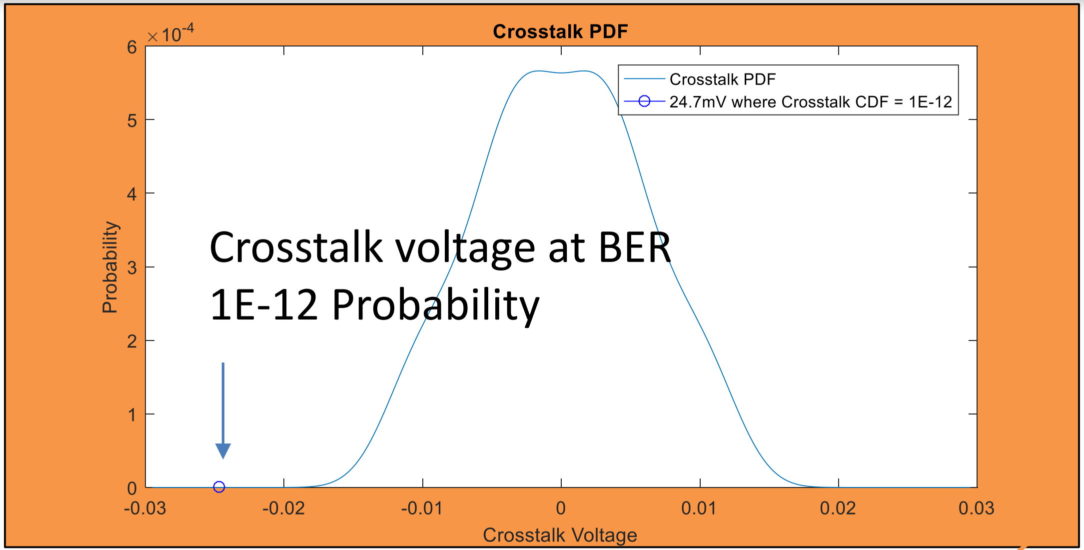
Effect of PWF Filter

Crosstalk ignored above this frequency

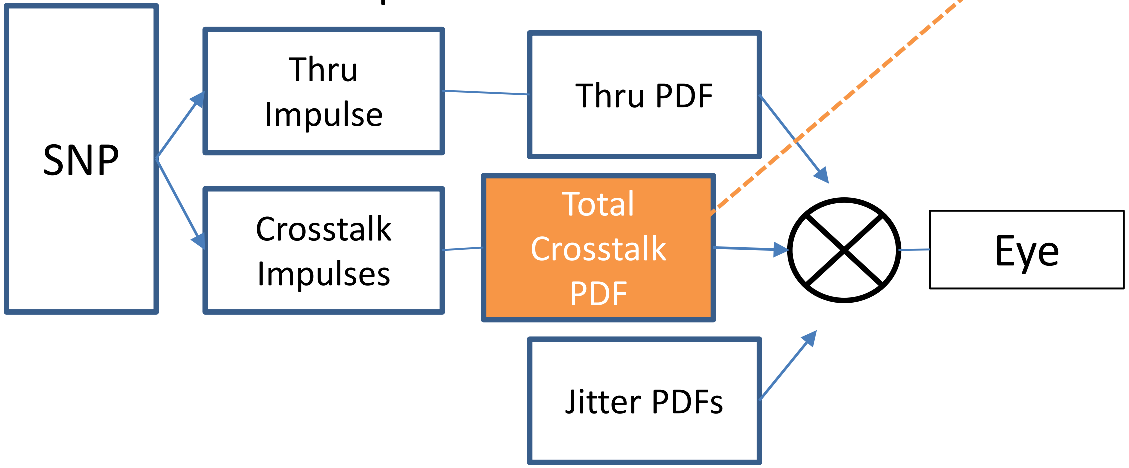
$$\sigma_{icn} = \sqrt{2 \cdot \Delta f \cdot \boxed{\sum_n PWF(f_n)} \cdot \boxed{\sum_x A_x^2 \cdot |SDD21XTK_x(f_n)|^2}}$$

Metric #2: Crosstalk PDF at BER

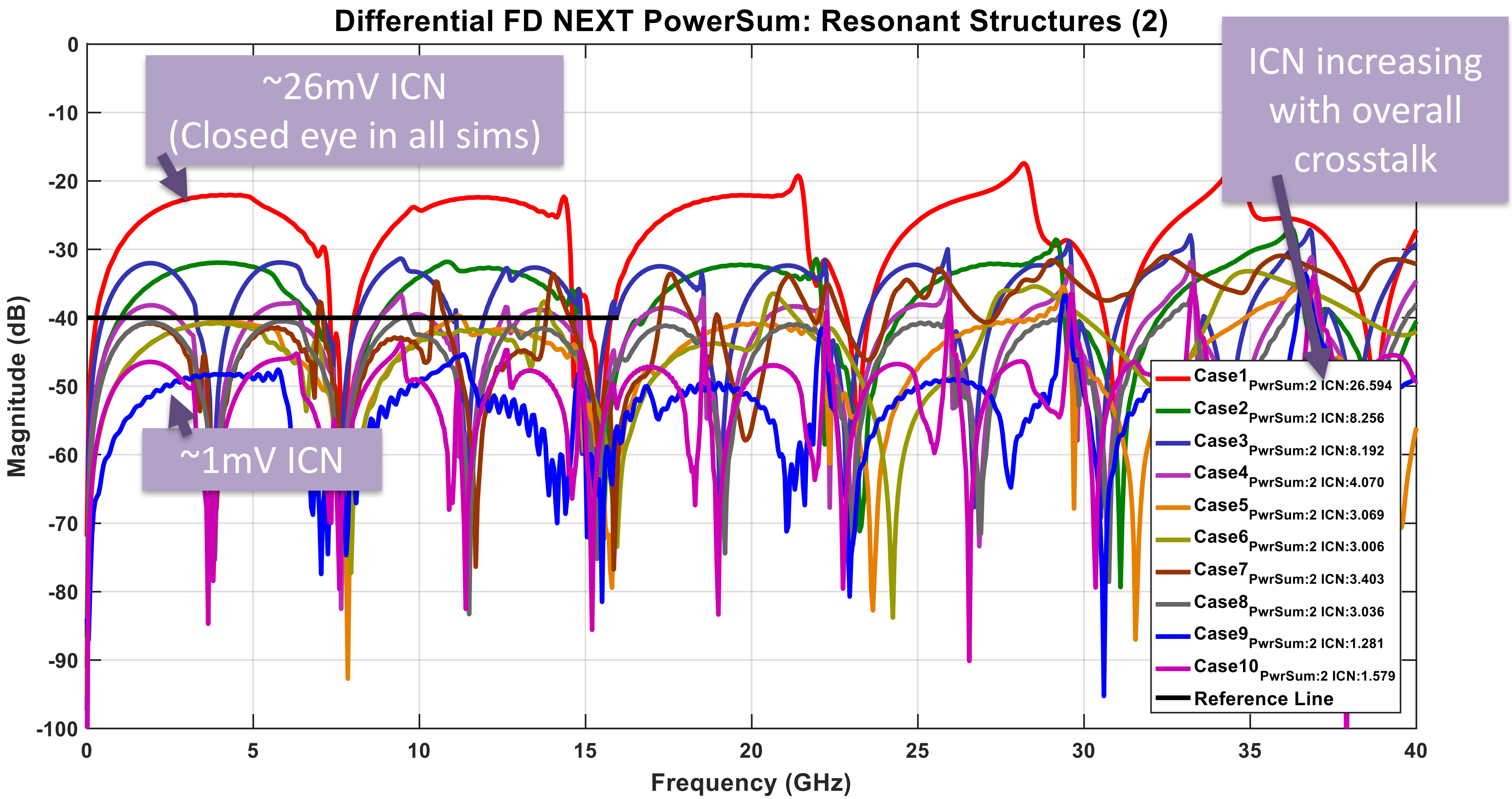
- **Take computation directly out of channel compliance**
  - Should correlate well
- **Existing tool Seasim**
- **Same concerns as reference channel:**
  - Measurement quality, combining, etc.



Gross Simplification of Seasim Flow

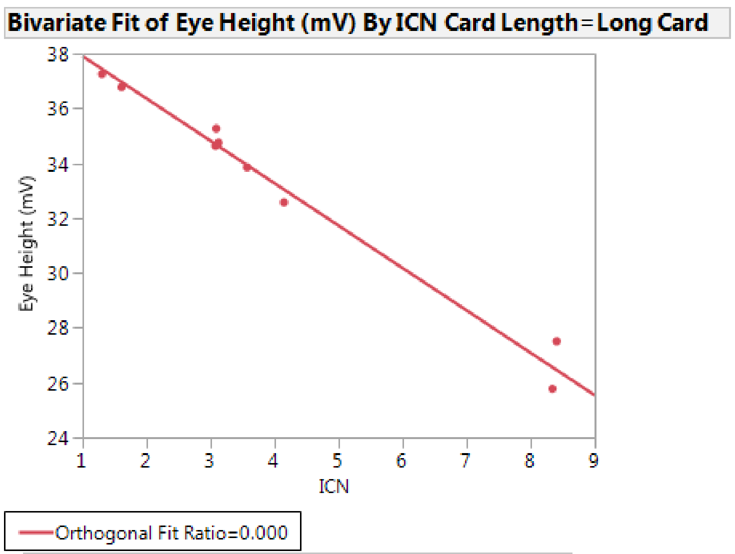


Preliminary Evaluation of Proposed Metrics: Connectors Under Consideration



Eye Opening vs. ICN: 4” Card Only

Eye Height

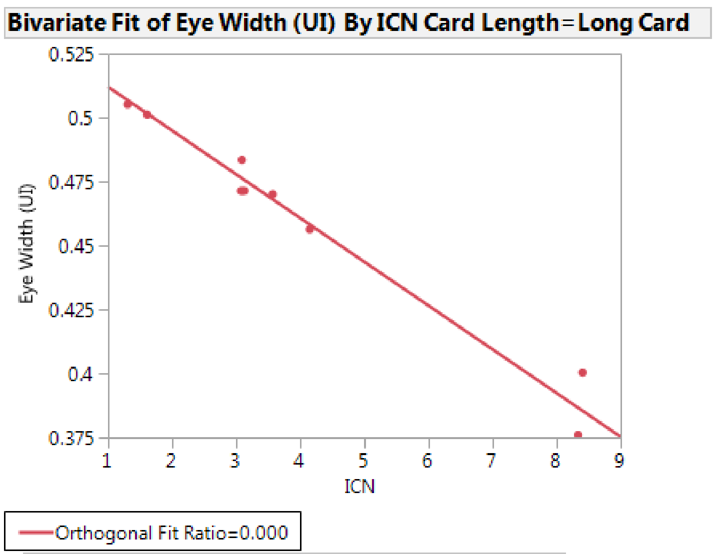


Orthogonal Fit Ratio=0.000

Variable	Mean	Std Dev	Variance Ratio	Correlation
ICN	4.074111	2.5929	0	-0.9907
Eye Height (mV)	33.1523	3.97063		

Intercept	Slope
39.44982	-1.54574

Eye Width



Orthogonal Fit Ratio=0.000

Variable	Mean	Std Dev	Variance Ratio	Correlation
ICN	4.074111	2.5929	0	-0.9858
Eye Width (mV)	0.459441	0.043663		

Intercept	Slope
0.529035	-0.01708

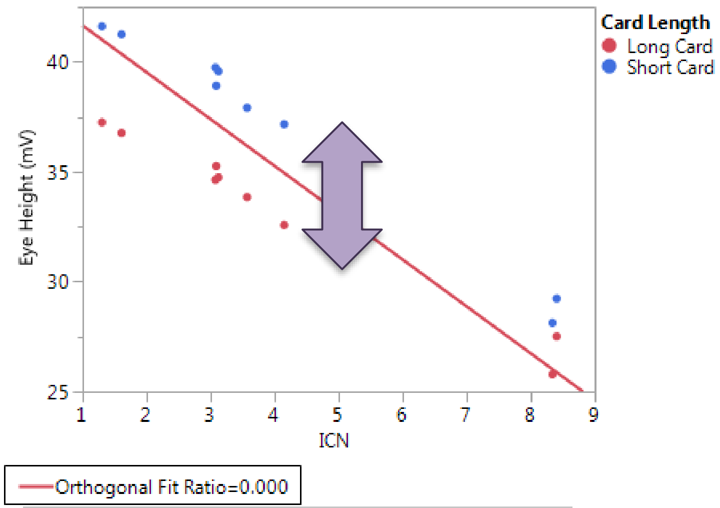
*Case 1, ICN= 27mV excluded, EH=0mV

Find a reasonable 1:1 relationship between EH\EW and ICN

Eye Opening vs. ICN: Now Add 2” and 4” Cards

Eye Height

Bivariate Fit of Eye Height (mV) By ICN



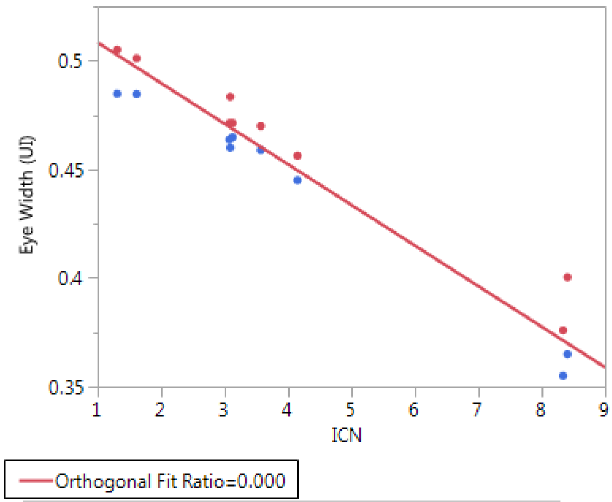
Orthogonal Fit Ratio=0.000

Variable	Mean	Std Dev	Variance Ratio	Correlation
ICN	4.074111	2.515482	0	-0.8953
Eye Height (mV)	35.1058	4.802409		

Intercept	Slope
43.79337	-2.13238

Eye Width

Bivariate Fit of Eye Width (UI) By ICN



Orthogonal Fit Ratio=0.000

Variable	Mean	Std Dev	Variance Ratio	Correlation
ICN	4.074111	2.515482	0	-0.9698
Eye Width (mV)	0.450939	0.045578		

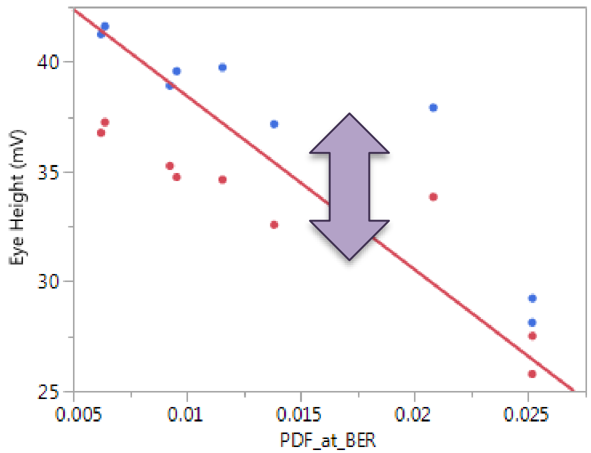
Intercept	Slope
0.527057	-0.01868

Vertical Spread is “scrap” or margin left on the table. This is always the challenge for connector-only requirements with unknown channel lengths

Eye Opening vs. X-Talk PDF at BER: Now Add 2” and 4” Cards

Eye Height

Bivariate Fit of Eye Height (mV) By PDF_at_BER



Orthogonal Fit Ratio=0.000

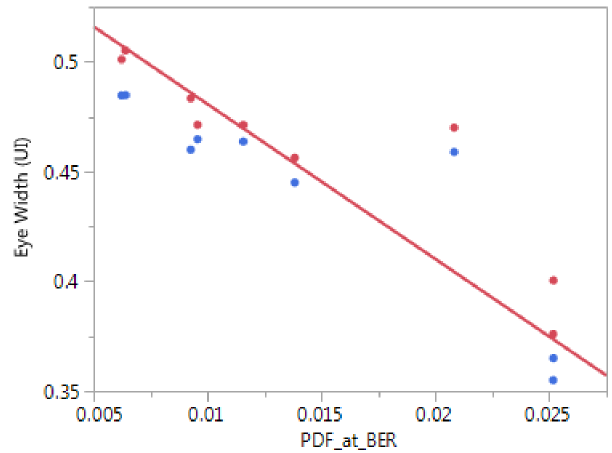
Orthogonal Fit Ratio=0.000

Variable	Mean	Std Dev	Variance Ratio	Correlation
PDF_at_BER	0.014226	0.007372	0	-0.8236
Eye Height (mV)	35.1058	4.802409		

Intercept	Slope
46.3578	-790.971

Eye Width

Bivariate Fit of Eye Width (UI) By PDF_at_BER



Orthogonal Fit Ratio=0.000

Orthogonal Fit Ratio=0.000

Variable	Mean	Std Dev	Variance Ratio	Correlation
PDF_at_BER	0.014226	0.007372	0	-0.8754
Eye Width (mV)	0.450939	0.045578		

Intercept	Slope
0.551406	-7.06246

Vertical Spread is “scrap” or margin left on the table. This is always the challenge for connector-only requirements with unknown channel lengths

ICN vs. Crosstalk PDF at BER:

- **R-squared correlations performed for EH and EW against both metrics**
- **ICN correlation performing better than Crosstalk PDF at BER (96.9% vs. 87.5% to EW)**
- **Correlation is strong – only crosstalk related variables in the system simulation**
  - This is intentional. We want to know if it correlates.
- **Adding more variables e.g. reflection will decrease correlation**
  - Useful if we want to quantify # of false negatives or false positives

Correlations

	ICN	PDF_at_BER	Eye Height (mV)	Eye Width (UI)
ICN	1.0000	0.9139	-0.8953	-0.9698
PDF_at_BER	0.9139	1.0000	-0.8236	-0.8754
Eye Height (mV)	-0.8953	-0.8236	1.0000	0.8069
Eye Width (UI)	-0.9698	-0.8754	0.8069	1.0000

Conclusion:

- A frequency domain mask may lead to false failures for sufficient 32GT/s connectors
- Discussed potential excursion permitting methods and reasons “for” or “against”
- Introduced “connector-like” simulation structure to provide control over frequency and magnitude of resonances
- Demonstrated strong relationship between system performance and favored ICN\PDF crosstalk metrics – a 90% correlation

Next Steps:

- **Verify ICN inputs make sense (Trise, RxBW, aggressor amplitude)**
  - What inputs improve correlation?
- **Ask other vendors to repeat the results**
- **Introduce more variables in the simulation**
- **Determine maximum amount of ICN that is permissible**
  - Find the right risk balance

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